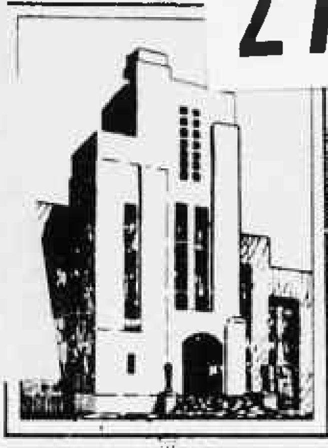

DEPARTMENT OF THE NAVY

DAVID TAYLOR MODEL BASIN

HYDROMECHANICS

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COMPARISON OF STANDARD AND SUBSIZE HY-80 DROP-WEIGHT SPECIMENS FOR VARIOUS CONDITIONS OF HEAT TREATMENT

by

M.L. Salive and A.R. Willner

STRUCTURAL MECHANICS LABORATORY

RESEARCH AND DEVELOPMENT REPORT

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ABSTRACT

This report evaluates the NDT temperatures of subsize and standard drop-weight specimens of HY-80 steel when the crack-starter bead is deposited prior to and after heat treatment. Also included are investigations of the effect of isothermal treatment on the crack-propagation characteristics of the crack-starter bead and the effect of direction of plate rolling on the specimens.

INTRODUCTION

A program[1] is currently underway at the David Taylor Model Basin for systematically determining the effects of various metallurgical factors on commercially produced HY-80 steels, military specifications MIL-S-16216.[2] Figure 1 outlines the essential phases of this program.

The present study was concerned with the NDT temperatures of subsize (5/8 in.) and standard (1 in.) drop-weight specimens when heat treated before or after depositing the crack-starter bead. The effect of isothermal treatment on the crack-propagation characteristics of the crack-starter bead and the effect of specimen directionality were also investigated for the subsize specimen.

BACKGROUND

The Navy Department considers drop-weight results (NDT) as one of the most important criteria for determining the notch toughness of steels and employs such data as quantitative values when evaluating materials for eventual use in the structural design of surface ships and submarines. Therefore, it is essential that test procedures and specimens be selected to give quantitative results.

Since Naval Research Laboratory normalization procedures[3, 4] are based on as-received material and because only a limited number of normalization tests were available on HY-80 steel, it was thought necessary to investigate the effect of specimen size using heat-treated subsize (5/8 in.) and standard (1 in.) drop-weight specimens.

In order to obtain quantitative data, the microstructure beneath the crack-starter bead should be representative of the microstructure of the metallurgical variable. It was felt that to achieve a representative specimen necessitated heat treating the test specimen with the crack-starter bead already applied. Accordingly, it was planned to investigate the temperature differences when the crack-starter bead was deposited prior to heat treatment and after heat treatment.

Another question that arose was whether when the crack-starter bead was deposited prior to heat treatment, the subsequent heat treatment would affect the crack-propagation

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[1]References are listed on page 9.

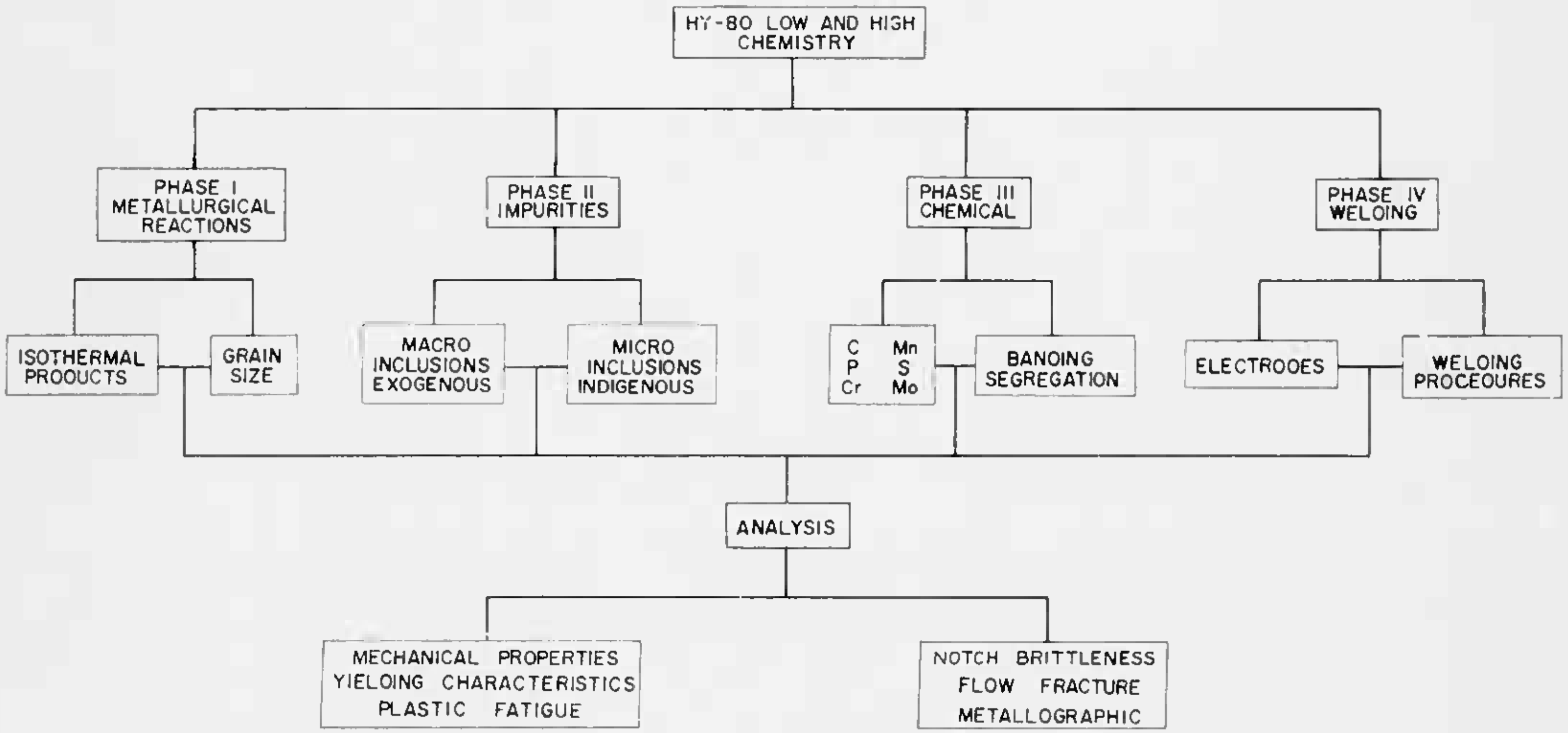

Figure 1 – Investigative Steps in the Study of HY-80 Steels

characteristics of the crack-starter bead. The 5/8-in. specimen was chosen to investigate the effects of nonmartensitic products. Within practical limits, this specimen permitted attaining various percentages of nonmartensitic products.

A previous Model Basin study[5] has indicated that the lower plateau of the longitudinal and the transverse Charpy V-notch energy-temperature-transition curves did not coincide. This raised the question as to whether directionality of the drop-weight specimen had an effect on the NDT temperature, and accordingly, an investigation of this factor was included in the present study.

MATERIALS AND PROCEDURE

STEEL PLATES

One-in. and 5/8-in. high-chemistry HY-80 plates from the same heat were used in this investigation. Their chemistry and mechanical properties, as furnished by the producer, are given in Tables 1 and 2.

TABLE 1

Chemistry of As-Received 1-In. and 5/8-In. HY-80 Steel Plate

(Furnished by the producer)

Location	C	Mn	P	S	Si	Ni	Cr	Mo
Ladle	0.14	0.32	0.015	0.016	0.27	2.80	1.52	0.41
Check	0.15	0.33	0.018	0.017	0.26	2.85	1.50	0.40

TABLE 2

Mechanical Properties of the As-Received HY-80 Steel Plate

(Furnished by the producer)

	5/8 in. (Plate Number 0157248A1)		1 in. (Plate Number 015723A1)	
	Longitudinal	Transverse	Longitudinal	Transverse
Tensile Strength, psi	111,800	115,500	109,400	112,250
Yield Strength, psi	84,910	87,370	93,600	94,230
Percent Elongation in 2 in.	29	23	24	23
Percent Reduction in Area	73.3	56.8	73.7	59.0
Charpy V-notch (–120 Deg F), ft-lb	73-100	–	76-94	–

TEST SPECIMENS

The standard (1 × 3½ × 14 in.) and subsize (5/8 × 2 × 5 in.) drop-weight specimens developed by the Naval Research Laboratory[4] were used; their widths were machined parallel to the direction of plate roll. However, for purposes of comparison, a number of subsize drop-weight specimens were machined with the 5-in. length parallel to the direction of major plate roll. "Hardex N" electrode was used to deposit the crack-starter bead. The crack-starter bead was laid parallel to the major dimension of the specimen. All crack-starter beads were notched perpendicular to the bead length and to within 0.07 in. of the original plate surface.

HEAT TREATMENT

The drop-weight specimens made from the 1-in. plate were normalized and then heat treated in an atmospheric controlled furnace. The specimens made from the 5/8-in. plate were heat treated in a neutral salt bath furnace. All furnace temperatures were controlled to within ± 5 deg F. These specimens had an ASTM micro grain size of eight or less.

EXPERIMENTAL TEST PROCEDURE

In determining the drop-weight NDT temperature, the test procedures outlined by the Naval Research Laboratory[4] were used. The hammer weight, drop distance, and stop distance used in this investigation are given in Table 3.

TABLE 3

Drop-Weight Constants Used in Testing
Standard and Subsize Specimens

	Standard	Subsize
Specimen Size	1 × 3 ½ × 14 in.	5/8 × 2 × 5
Weight of Hammer	223 lb	123 lb
Drop Distance	5 ft	2 ft
Stop Distance	0.30 in.	0.075 in.
Test Span	12 in.	4 in.

The data given in Table 3 represent the minimum test conditions in which the test specimens were found to contact the anvil stop and give the required crack opening of 12 to 18 mils in the crack-starter bead.

The low-temperature baths for the drop-weight specimen were controlled to within ±3 deg F. All temperatures were recorded on a calibrated Honeywell recording pyrometer. After specimens reached the test temperature, they were held there for 45 min prior to testing. Thermocouples attached to pilot specimens indicated no loss in temperature during the time required to remove the specimen from the bath and begin the test.

A drop-weight specimen was considered broken when the crack emanating from the crack-starter bead propagated across the surface and down one side of the specimen. In order to determine the NDT temperature, a temperature increment of 10 deg F was used to bracket NDT.

Since a complete analysis of tensile properties and their relationship to NDT will be given in a subsequent report, no tensile tests were made on these specimens.

TEST RESULTS

All data are presented in tabular form to permit a simple and fast comparison of any specimen with its NDT temperature. The conditions and treatment given to each group of, specimens and their respective test results (NDT) are given in Tables 4 and 5.

COMPARISON OF STANDARD AND SUBSIZE SPECIMENS OF AS-RECEIVED HY-80 STEEL

A series of standard (1 in.) and subsize (5/8 in.) specimens were machined from the as-received 1-in. plate, in addition, comparative subsize specimens were machined from the 5/8-in. plate. A crack-starter bead was deposited on the surface in accordance with the Naval Research Laboratory procedure.[3, 4]

The NDT temperature of a subsize specimen cut from the 1-in. as-received plate agreed with the NDT temperature of the standard specimen within the ± 10 deg F tolerance of the test as predicted by Puzak and Babecki;[3, 4] see Tests 1 and 2, Table 4.

The NDT temperatures of subsize specimens cut from 1-in. and 5/8-in. as-received plates were the same; see Tests 2 and 3, Table 4.

COMPARISON OF THE EFFECTS OF DEPOSITING THE CRACK-STARTER BEAD PRIOR TO OR AFTER HEAT TREATMENT OF THE TEST SPECIMEN

When tested, heat-treated standard and subsize drop-weight specimens having the crack-starter bead deposited prior to heat treatment indicated a 20-deg F difference in measured NDT temperatures; see Tests 4 and 5, Table 5. This difference in NDT temperature is attributed to a slight difference in hardness, i.e., 230 and 211 BHN for subsize and standard specimens, respectively.

Drop-weight specimens on which the crack-starter bead was deposited before heat treatment showed lower NDT temperatures than those specimens welded after heat treatment; see Tests 6 through 9, Table 4.

TABLE 4

Effects of Drop-Weight Specimen Sizo on the NDT Temperature of HY-80 Steel and tho Effects of Hoat Treatment on the Crack-Initiating Properties of tho Crack-Starter Boad

Test	Plate Identification	Original Plate Thickness in.	Drop Weight Specimen Size in.	Heat Treatment* Isothermal Treatment Temperature deg F	Heat Treatment* Isothermal Treatment Time sec	Heat Treatment* Water Quench	Heat Treatment* Tempering Temperature** deg F	NDT Temperature (deg F) Crack-Starter Bead Deposited Before Heat Treatment	NDT Temperature (deg F) Crack-Starter Bead Deposited After Heat Treatment
1	0157235A1	1	1 × 3½ × 14	–	–	–	–	–	–160
2	0157235A1	1	5/8 × 2 × 5	–	–	–	–	–	–170
3	0157248A1	5/8	5/8 × 2 × 5	–	–	–	–	–	–170
4	0157235A1	1	1 × 3½ × 14	–	–	X	1250	–210	–
5	0157235A1	1	5/8 × 2 × 5	–	–	X	1250	–190	–
6	0157248A1	5/8	5/8 × 2 × 5	–	–	X	1150	–210	–170
7	0157248A1	5/8	5/8 × 2 × 5	875	1600	X	1150	–200	–170
8	0157248A1	5/8	5/8 × 2 × 5	875	1600	X	600	– 70	– 50
9	0157248A1	5/8	5/8 × 2 × 5	1200	8500	X	1150	–210	–200

* Austenitizing temperature 1640 deg F – held ½ hour.

** Tempered for 1 hour, then water quenched.

TABLE 5

Effects of Major Plate Rolling Direction on the NDT Temperature, Determined Using Subsize Drop-Weight Specimens Prepared from HY-80 Steel Plate (0157248A1) and then Heat Treated

Test	Heat Treatment* Isothermal Treatment Temperature deg F	Heat Treatment* Isothermal Treatment Time sec	Heat Treatment* Water Quenched	Heat Treatment* Tempering Temperature** deg F	NDT Temperature (deg F) Longitudinal†	NDT Temperature (deg F) Transverse††
A	–	–	X	900	–110	–110
B	–	–	X	1000	–120	–110
C	–	–	X	1150	–220	–210
D	–	–	X	1250	–255	–255
E	–	–	X	1270	–240	–240
F	875	1,600	X	1150	–215	–200

* Austenitizing temperature 1640 deg F – held ½ hour.

** Tempered for 1 hour, then water quenched.

† Direction of plate roll parallel to 5 in. length of specimen.

†† Direction of plate roll perpendicular to 5 in. length of specimen. (Standard Specimen)

EFFECTS ON NDT TEMPERATURE OF MAJOR PLATE ROLLING DIRECTION IN DROP-WEIGHT SPECIMEN

Table 5 indicates the effects of rolling direction for a series of quenched and tempered subsize drop-weight specimens and on one set of isothermally treated drop-weight specimens prepared from the 5/8-in. HY-80 steel plate. Figure 2 presents an example of the results of directional subsize NDT tests plotted on their respective Charpy V-notch-energy-transition curves.

The results indicate that drop-weight specimen directionality had a negligible effect on the NDT temperature.

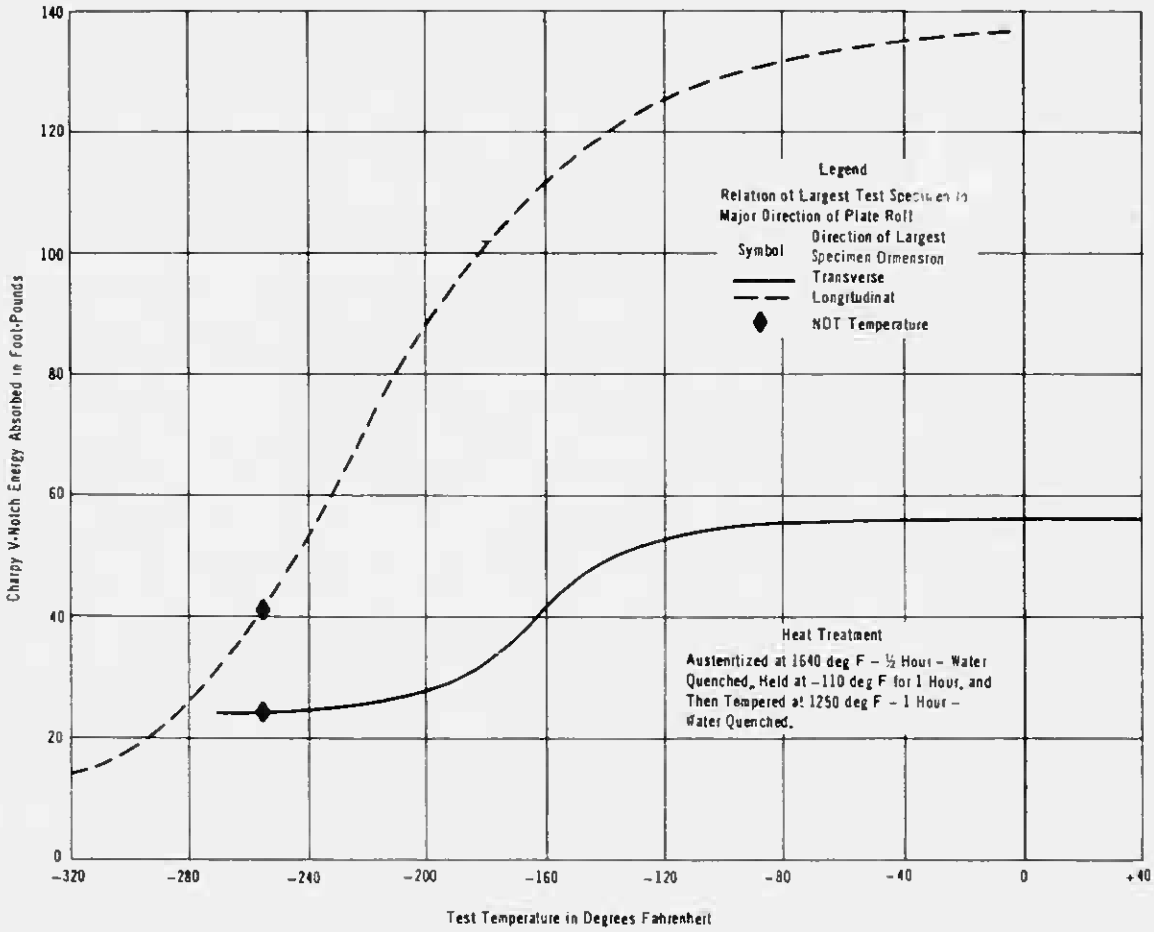

Figure 2 – Effects of Specimen Direction Relative to the Major Direction of Plate Rolling, 5/8-In. Plate, on the Charpy V-Notch Energy Transition and on the NDT Temperature of HY-80 Steel

DISCUSSION

The results of this study indicate that depositing the crack-starter bead on the subsize drop-weight specimen prior to heat treatment tended to decrease the NDT temperature 10 to

40 deg F below that of specimens in which the crack-startor bead was deposited after heat treatment. This decrease is attributed to the uniform microstructure in the plate material beneath the weld deposit. The crack-starter bead deposited on the subsize drop-weight specimen after heat treatment develops a complex microstructure consisting of a multiplicity of large and small grains and various quenched and tempered products.

Although the subsize drop-weight bars which were welded prior to heat treatment had lower NDT temperatures than those welded after heat treatment, it should not be assumed that all ferrous materials will exhibit the same relative difference. That is, some high-strength steels may exhibit an erroneously lower NDT when welded after heat treatment.

It should be noted that the Charpy V-notch maximum energy absorbed (Figure 2) was lower than that reported for the same heat treatment in a previous study of a HY-80 steel from another heat (Figure 5 of Reference 5). The metallurgical factors affecting the maximum energy shelf will be discussed in a subsequent report.

Although the lower energy plateau of the longitudinal and transverse Charpy V-notch curves depicted in Figure 2 do not coincide, the NDT-temperature data for the subsize drop-weight specimens do not show this sensitivity to directionality.

Even though the major plate rolling direction of HY-80 steel had no effect on the NDT temperature of drop-weight specimens, it was decided to use the Naval Research Laboratory standard subsize specimen (5/8 × 2 × 5 in.) with the 2-in. width parallel to the direction of plate roll for all phases of subsequent studies as depicted in Figure 1.

The procedure of depositing a crack starter on the test specimen prior to heat treatment will be followed for all drop-weight specimens prepared in the studies planned for Phases I, II, and III. The decrease in NDT temperature by such a prepared specimen is, as already indicated, due to the uniform microstructure in the plate immediately below the crack-starter bead deposit. This procedure permits a true evaluation of the relative effects of metallurgical variables on the notch toughness of HY-80 base material.

In Phase IV, the effects of welding combined with controlled metallurgical variables will be studied; the crack-starter bead will be deposited prior to testing (subsequent to heat treatment) in order to obtain an overall evaluation.

CONCLUSIONS

The following conclusions are made for the subsize drop-weight specimens made from the 5/8 in. HY-80 material used in the Model Basin investigations:

1. The results of this study support the Naval Research Laboratory[3,4] contention that the subsize specimen will predict the NDT temperature of the reference standard specimen within ±10 deg F.

2. Depositing the crack-starter bead on the subsize drop-weight specimen before heat treatment gives a true evaluation of the NDT properties of HY-80 base plate.

3. Depositing of the crack-starter bead on the subsize drop weight specimen after heat treatment increases the NDT temperature of the HY-80 base plate 10 to 40 deg F.

4. Isothermal treatment of the suhsize drop-weight specimen after the crack-starter bead is deposited has no effect on the crack-initiating properties of the crack-starter bead.

5. Drop-weight specimen directionality has no effect on the NDT temperature of HY-80 steel.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of Mr. Richard E. Jones, who was instrumental in setting up and calibrating the drop-weight testing machine and who performed all the tests.

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